Upsilon Production In p-p Collisions at LHC

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Abstract

This is a continuation of recent studies of $\Upsilon(nS)$ production at the LHC in p-p collisions. Our previous studies were for 2.76 TeV, while the present predictions are for 7.0 TeV collisions.

In our recent work[1] on heavy quark state production in p-p (proton-proton) collisions we calculated $\Upsilon(nS)$ production using the color octet model, which was shown to dominate color singlet production of heavy quark states in p-p collisions[2, 3]. We use the treatment formulated by Nayak and Smith[4]. The main objective of this work is to study how our mixed hybrid theory differs from the standard quark model for $\Upsilon(nS)$ production. In our theory[5] the $\Upsilon(1S)$ and $\Upsilon(2S)$ states are conventional $b\bar{b}$ states, while the $\Upsilon(3S)$ is 50% standard $b\bar{b}$ and 50% hybrid. See Ref[1] for a brief sumary of this theory. For the LHC production we used an energy of 2.76 TeV, corresponding to the publication of CMS results, mainly for Pb-Pb collisions[6], and calculated the ratios of cross sections $\frac{\sigma(\Upsilon(2S))+\sigma(\Upsilon(3S))}{\sigma(\Upsilon(1S))}$, since the 2S and 3S states were not resolved for p-p collisions in Ref[6]. In light of new results by the CMS Collaboration for p-p collisions at at 7.0 Tev[7], with a much larger data set, in which both the $\Upsilon(2S)$ and $\Upsilon(3S)$ ratios to the $\Upsilon(1S)$ cross sections were measured, we submit this note.

Although we use the color octet model, we note that there have been many publications on the color singlet vs the color octet model. For details of the color singlet model see the review by Lansberg[8] in which the color singlet model for J/Ψ and Υ production is found to be much larger than the color singlet model. This approach, however, involves complicated calculations with many higher order diagrams. For example, Lansberg *et al*[9] found higher order processes which are color-octet-like to be as large as color singlet ones. As stated above, in Refs[2, 3] the color octet processes were found to be much larger than the color singlet for heavy quark meson production. Also, it should be noted that gluonic processes are dominant for both singlet and octet models, and our results are based on the hybrid nature of certain heavy quark states, with valence gluons[1]. Since we only find ratios of matrix elements, our mixed hybrid model results might be similar for the singlet model as the octet model, an interesting topic for future work.

We now briefly review the theory. Using the color octet model with scenerio 2 (see Refs[1, 4]), the cross section for helicity $\lambda = 0$, which is dominant, is

$$\sigma_{pp\rightarrow\Upsilon(\lambda=0)} = A_v \int_a^1 \frac{dx}{x} f_g(x, 2m) f_g(a/x, 2m) \ , \tag{1}$$

where $f_g(x, 2m)$ are the gluonic distributions evaluated at 2m=10GeV, corresponding to the bottom quark mass. The quantities $a = 4m^2/s$ and $A_\Upsilon = \frac{5\pi^3\alpha_s^2}{288m^3 s} < O_8^\Upsilon(^1S_0) >$ in scenerio 2. Note that the quantity a decreases with energy, increasing the cross section, while the quantity A_Υ decreases with energy, with a net result that in the octet model the cross section decreases with energy. On the other hand, the cross cections depend on the scenerios[1], and the only meaningful calculations in the present work are in the ratios of cross sections.

As derived in Ref[1], in the standard model, using harmonic oscillator wave functions, since with bottom quarks nonrelativistic theory is adequate, we find for the ratios of cross sections at 7.0 TeV in the standard model

$$\begin{aligned} \sigma(\Upsilon(2S))/\sigma(\Upsilon(1S)) &\simeq 0.27 \ \text{standard} \\ \sigma(\Upsilon(3S))/\sigma(\Upsilon(1S)) &\simeq 0.04 \ \text{standard} \ , \end{aligned} \tag{2}$$

while in the mixed hybrid picture the ratio $\sigma(\Upsilon(2S))/\sigma(\Upsilon(1S))$ is 0.27 as in the standard model, while (see Ref[1] for hybrid vs standard for $\Upsilon(3S)$ production)

$$\sigma(\Upsilon(3S))/\sigma(\Upsilon(1S)) \simeq 0.1 \ \text{mixed hybrid} \ . \tag{3}$$

The CMS results at 7.0 TeV are[7]

$$\begin{aligned} \sigma(\Upsilon(2S))/\sigma(\Upsilon(1S)) &\simeq 0.26 \pm 0.02 \pm 0.04 \ \text{CMS} \\ \sigma(\Upsilon(3S))/\sigma(\Upsilon(1S)) &\simeq 0.14 \pm 0.01 \pm 0.02 \ \text{CMS} \ . \end{aligned} \tag{4}$$

Therefore one sees that the CMS results for the $\sigma(\Upsilon(3S))/\sigma(\Upsilon(1S))$ ratio are in disagreement with the standard quark model, but agree within errors with the mixed hybrid theory. Note that new CMS results for $\Upsilon(nS)$ cross sections with much more data are to be published soon[10], and are in agreement with the data of Ref[7].

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